FLOOD-PRODUCING RAINS IN NORTHERN AND CENTRAL CALIFORNIA, DECEMBER 16–26, 1955

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1. INTRODUCTION

Northern and central California was the scene of unusually heavy rains and destructive flooding during the period December 16–26, 1955. Rainfall amounts exceeded many existing records and flood conditions were described as the worst in the history of northern California. Preceded by periods of moderate to heavy rains during the first half of the month, the record-breaking deluge fell on rain-soaked soil and drained into already rain-swollen streams. Rivers overflowed their banks and went on to cause the costliest flood on record for the area. News reports listed 66 deaths as a result of the floods, and preliminary property damage estimates exceeded $150,000,000. Thousands of people were forced to evacuate their homes, five small towns were reported "wiped out," and transportation was disrupted by high water, slides, and bridge washouts.

December climatological data immediately available emphasized the intensity of this storm period with a number of new rainfall records. Oakland and Blue Canyon reported December 1955 as the wettest month on record. Fresno, Mt. Shasta, and Medford reported the wettest December on record. Stations with longer histories found comparisons in the last century: San Francisco reported the wettest December since 1889 and Sacramento since 1867.

The occurrence of moderate to heavy rains in this part of the country is generally regarded as a normal wintertime feature and has been described many times in literature. Several investigators, Vernon [1], Martin and Hawkins [2], and Hughes and Roe [3], to name a few, have found that the rain mechanism for northern and central California is largely due to topography, a strong southwesterly flow, and an ample supply of moisture. Since the rainfall in this case was unprecedented, it is surmised that the interaction of these factors was excessive both in time and amount. Therefore, this article is primarily concerned with a discussion of some of the more pertinent synoptic and climatological aspects of the heavy rains and ensuing floods. Included in the discussion are comments on the persistency of the synoptic situation, distribution and intensity of Low centers passing over northern California, relationship of the jet stream, strength of vertical velocities, temperature features, and the importance of strong low-level flow. Furthermore, rainfall amounts are compared with past records and related to both gradient and topography. Most of the synoptic charts used in this article were reproduced from the operational charts of the National Weather Analysis Center. Also, it should be emphasized that much of the rain and flood data were based on preliminary reports and subject to future revision. More complete data will be printed in *Climatological Data, National Summary* for December 1955.

2. ANTECEDENT CONDITIONS

For the first two weeks of December, the 500-mb. flow pattern over northern California was predominantly west to northwest which permitted several short-wave systems to pass onto the Pacific coast. Specifically, one sea level Low passed onshore just north of Crescent City on December 1, and six occluded fronts passed over northern and central California during the 2-week period. Other Low centers entered either the coast of Washington or British Columbia. These minor storms produced moderate to occasionally heavy precipitation along the Pacific coast area north of Monterey Bay. Many stations received more than half their normal December rainfall by the 14th (table 2). At least two stations, Fresno and Oakland, received more than their December normal by midmonth, and several other stations received nearly as much. These antecedent rains soaked the soil, filled the streams, and prepared the scene for destructive flooding.

3. SYNOPTIC FEATURES DECEMBER 16–26

Around the middle of December, the 500-mb. flow pattern exhibited a change in regime. A flat persistent ridge along the Pacific coast moved inland, and the flow over northern and central California became southwesterly. At the same time, a blocking High cell in the Kodiak-Bering Sea area began increasing in intensity, and a pronounced trough was established in the eastern Pacific Ocean. (See article by Andrews [4] on the mean circulation pattern.) In general, this trough extended from the Alaska Panhandle to Hawaii. 500-mb. Low centers appeared in this trough, 600 to 700 miles west of the Seattle area, on December 15, 18, and 24. These Lows moved slowly eastward or northeastward and were absorbed within two or three days into the circulation of a large Low pressure system centered over northern Canada. Moving eastward with the Low of the 24th, the persistent trough passed over the Pacific coast on December 27.

At the surface, the first Low of the series moved over the Oregon-Washington coastline on the 16th and filled. It was accompanied by a weak trough over northern California that caused some light precipitation on the 15th and slightly larger amounts on the 16th. Rainfall amounts with this first Low were insignificant when compared with amounts that fell later.

On December 17, the rainfall intensity became a little heavier. This rain occurred in advance of an occluding Low center located about 1,600 miles west of San Francisco on December 16. Reaching the Pacific coast by the 18th, this Low and accompanying fronts (fig. 1a) was immediately followed by a wave of considerable vigor on December 19. The surface and 500-mb. features are shown in figure 2a. The strong pressure gradient associated with this wave created high winds at the surface and upper levels. Forty to sixty knot winds were reported by stations along the northern coast of California and by ships 100 to 200 miles off shore. At Oakland, the 850-mb. winds reached a maximum speed of 65 knots on the 19th. The presence of these strong winds plus a modest influx of moist tropical air produced exceedingly heavy rains over northern California. Somewhat smaller amounts fell over central California as the accompanying frontal system pushed southeastward (fig. 1a) and frontalized near Fresno.

Stations in an area from Crescent City to a point south of Point Arena and thence inland to Sacramento and Mt. Shasta reported more precipitation for the 4-day period December 17–20 than they did for the next 4 days, the period of heaviest rainfall for the remainder of California northwest of Bakersfield. A 24-hour total of 3.27 inches between the 18th and 19th at the Sacramento City Office set a new December record.

The second surge of heavy rain began on December 21. Late on this day, an increase of warm moist air and strong southwest winds over northern California were associated with a fairly intense occlusion crossing the Oregon-Washington coast (fig. 1b). In addition to this frontal system, another occlusion was located about 900 miles west of California and a developing wave in the Johnson Island area. By December 22, the second occluded front had passed over northern California (fig. 2b); and the wave was racing toward the Pacific coast. Both the 500-mb. contours and the surface isobars indicated a long tropical fetch, a very important factor in the California rain mechanism. The 18,800-ft. 500 mb. contour extended from the latitude of the Hawaiian Islands eastward to Oakland and Sacramento. North of the Hawaiian Islands, the confluence of warm and cold air created a very strong jet stream from the south Pacific Ocean to the coast

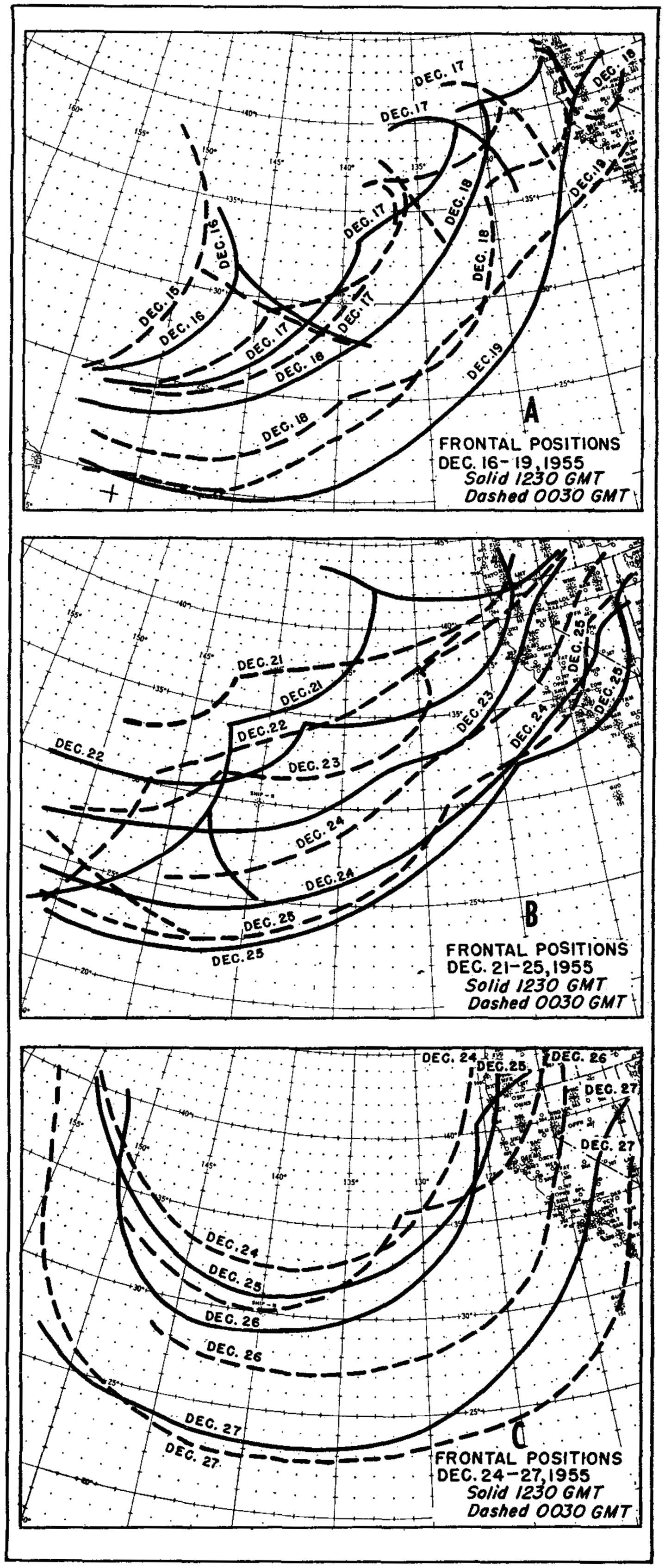

FIGURE 1.—The progression of frontal systems associated with the three main rain periods: (a) December 16–19, (b) December 21–25, and (c) December 24–27. Solid lines represent positions at 0430 PST and dashed lines 1630 PST. Fronts with the first two rain periods had a more southerly trajectory and moved faster than those in the final period.

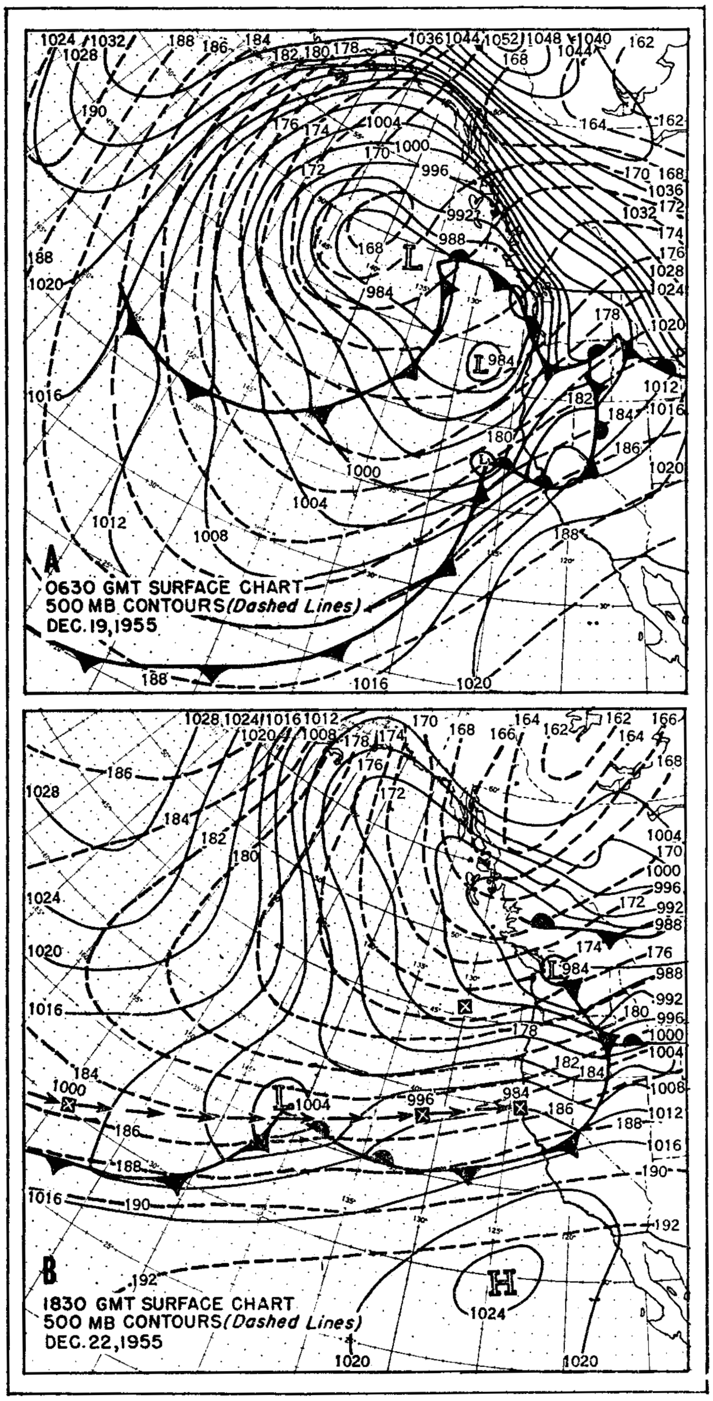

FIGURE 2.—Sea level and 500-mb. synoptic patterns related to the two periods of heaviest rainfall: (a) 0630 GMT surface chart for December 19 with 500-mb. contours for 0300 GMT in dashed lines, and (b) the 1830 GMT surface chart for December 22 with 1500 GMT 500-mb. contours. The December 19 chart represents a typical rainfall map for northern California with a strong southwest flow along the Pacific coast. On the December 22 chart, note the pronounced tropical fetch and the unusually rapid movement of the Pacific wave as indicated by its 6-hourly positions (squares).

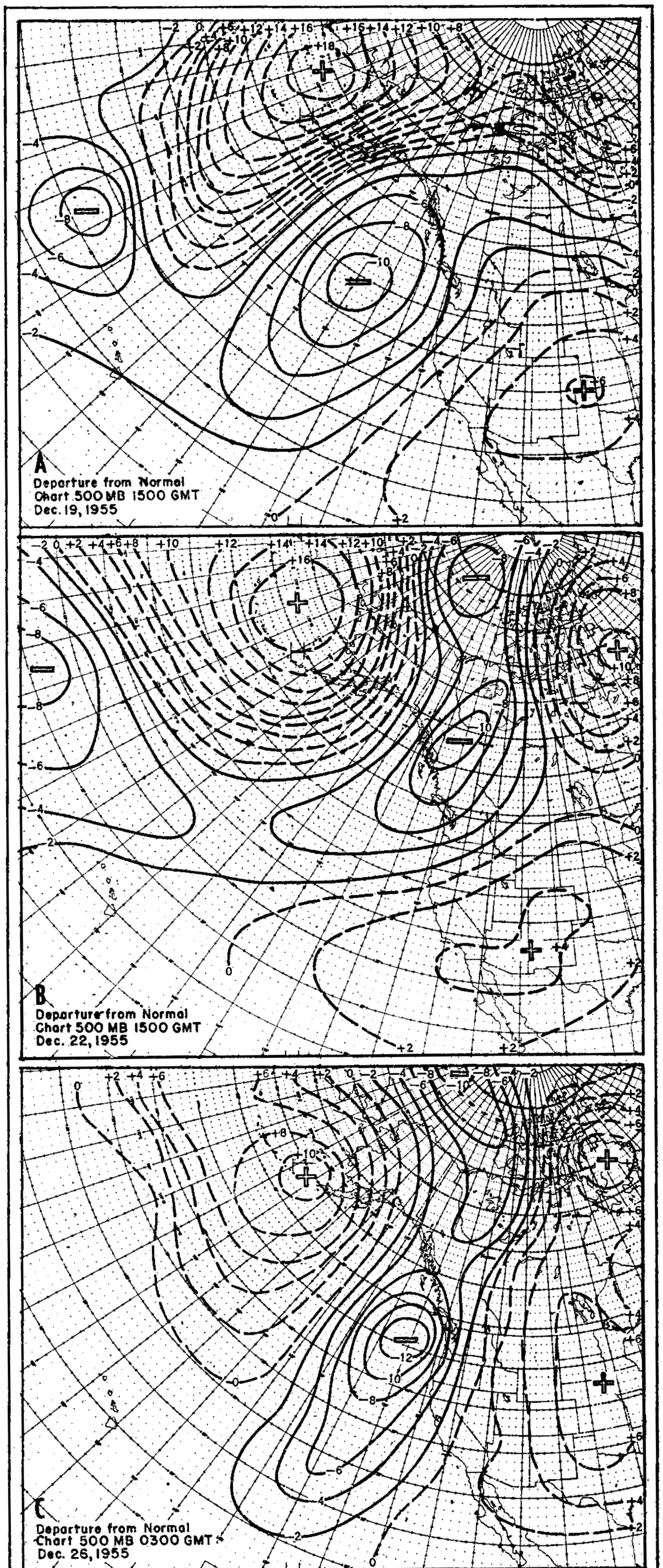

FIGURE 3.—Strength of blocking action in the Pacific is indicated by the departures of 500-mb. heights from normal for (a) 1500 GMT, December 19, (b) 1500 GMT, December 22, and (c) 0300 GMT, December 26. Values are in 100's of feet.

of North America. The wave from Johnson Island accelerated as it moved into this strong flow, traveling approximately 2,375 miles in 24 hours or nearly 100 m. p. h.

It was during this period that newspapers reported that 100 m. p. h. headwinds had almost halted all Pacific flights between California and Hawaii. One airline reported that the strong winds extended as low as 6,000 feet and that it was impossible to get over or around them. The anemometer on the Richmond-San Rafael Bridge registered 90 m. p. h. at 2230 P. S. T. on December 22 and again at 0200 P. S. T. December 23; at no time during that night was it less than 60 m. p. h.

This Low center was the most intense of the period, reaching a central pressure of 984 mb. just prior to passing onshore. As it moved rapidly eastward, Red Bluff reported its lowest sea level pressure on record. The intense precipitation attributed to this Low was largely due to the fact that it had a greater influx of moist tropical air than any of its predecessors. Too, in addition to strong orographic lifting, the tropical air was subjected to maximum lifting in the apex of the occluding warm sector located over northern California.

At Blue Canyon between December 21 and December 22, the 24-hour rainfall totaled 9.31 inches to set a new record. Their previous 24-hour maximum was 8.66 inches in November 1950. The progressive southward movement of the heaviest precipitation is shown in figures 9 and 10. This storm even broke rainfall records on the southern coast of California where Santa Maria, with a 13-year record, reported a 24-hour maximum of 3.07 inches between December 24 and December 25. This maximum broke the previous record of 2.55 inches established in January 1943.

On December 24, before the frontal systems from the previous storm had moved out of southern California (fig. 1b), synoptic features indicated that another surge of rainfall was imminent. At this time, a Low in the Gulf of Alaska began to dominate the situation by moving slowly southeastward and tightening the gradient over northern California. A weak occluded front pushed over the Pacific coast on December 25 (fig. 1c) and was followed approximately 24 hours later by a wave cyclone. This wave passed onshore near Ukiah, and its accompanying cold front was the last of the series to cross California. Coming from the Aleutian area and having a much shorter trajectory over warmer water than its predecessors, this Low system yielded about half as much rain as the others.

4. BLOCKING ACTION IN THE PACIFIC OCEAN

One of the most important broadscale features contributing to the extremely heavy rainfall in northern California was the blocking action of the 500-mb. High in the Aleutian area. The importance of this block is that it forced eastward-moving Pacific cyclones to take a southerly path over the warm Pacific Ocean. There the Lows gathered an influx of moist tropical air before proceeding to the North American coast.

Andrews [4] has written that a blocking tendency had existed in the North Pacific area since late October. It was not, however, until December 15 that the block began to achieve major proportions. Strong 500-mb. departures from normal heights were noted on December 19 (fig. 3a) ranging from a positive 1,800 ft. in the Bering Sea to a negative 800 to 1,000 ft. in the eastern Pacific trough. Large negative departures were also present in the south Pacific area. While not record departures, these values emphasized the strength of the block. On December 22, the departures (fig. 3b) were not as large as those of the 19th, but certainly indicated that the block was well established. By December 25, the departures (fig. 3c) showed that the block was weakening; the large departures in the Bering Sea had split, decreased to 1,000 ft., and were moving off to the southeast. This strong block persisted for 11 or 12 days, somewhat longer than normal, and thereby permitted more than the usual number of Lows to reach the Pacific coast.

5. DISTRIBUTION OF LOW CENTERS

During the period December 16–26, the number of Low centers that passed over the Pacific coast between San Francisco and Portland was larger than normal. It is shown in figure 4b that it is not uncommon for Lows to pass over this area during the winter months with most of the Lows entering the coast either near Crescent City or Portland. A study of storm tracks found in the *Monthly Weather Review* from 1940 to 1955 revealed that a maximum of eight Low centers have entered this stretch of coast during any one season from October to March. January, not December, had the highest incidence with four Lows in 1952 and again in 1941. In this case, three Low centers entered the coast between San Francisco and Portland, the largest number for any December in over 25 years. Low pressure centers reached the coast on December 16, 19, and 22, giving a time lapse between centers of three to four days. In order to find a comparable frequency, it was necessary to go back to the storm of March 1907. The report [5] on this storm said that three wave cyclones moved directly across the Sacramento Basin between the evening of the 16th and the night of the 19th, nearly one a day. While the interval between Lows during the December 16–26 period was not record breaking, it was a little shorter than normal. The usual interval for Lows entering the coast of northern California and Oregon appears to be about 5 to 10 days.

Another interesting feature about the Lows in this case was their intensity. The Low of the 22d had a central pressure of 984 mb., making it the deepest Low in twelve years. The total number of Lows to enter the coast each year since 1940 and their lowest pressure is shown in figure 4a. The deepest Low in the past fifteen years was 983 mb. in January 1943.

6. JET STREAM RELATIONSHIP

The position of the jet axis over the Pacific coast was

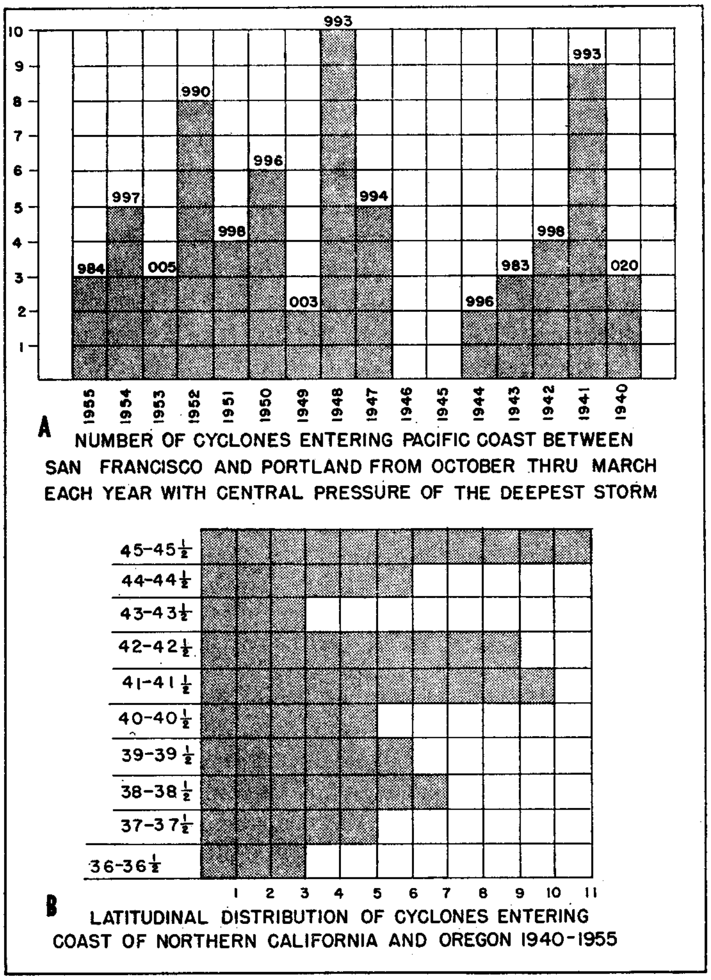

FIGURE 4.—(a) Annual number of Lows entering the Pacific coast between San Francisco and Portland since 1940 for the season October through March. Central pressure of the season's deepest storm is indicated above each bar. The 984-mb. Low of December 22 ranks with the intense Low of 1943. (b) Latitudinal distribution of Lows entering the northern coast of California and Oregon for the period 1940–1955.

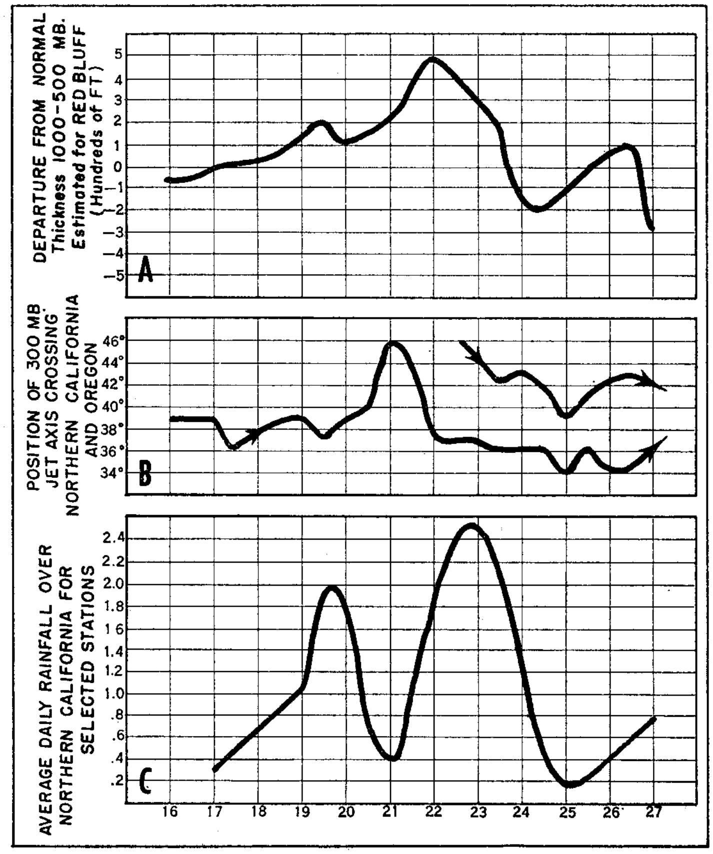

FIGURE 5.—Chronological relationship (a) estimated departures of 1,000–500-mb. thickness from normal, (b) latitudinal position of the 300-mb. jet axis over the Pacific coast, and (c) average daily rainfall for selected stations in northern and central California.

closely related to the rainfall intensity over northern and central California. Most of the heavy rainfall occurred north of 37° N. latitude, and the 300-mb jet axis appeared to be near this line during periods of intense precipitation. (figs. 5b and 5c). This pattern showed general agreement with Starrett's [6] model which placed the area of maximum precipitation ahead of a trough and just to the north of the jet stream with a secondary maximum south of the jet.

Heavy precipitation occurred on December 19 as the polar jet axis dropped to 37° N. On December 20–21, the rain decreased significantly as the jet stream shifted north to the Portland area. During the period of greatest average rainfall, December 22–23, the jet was located near 36° N., or south of Santa Cruz. As the jet continued to shift southward toward Santa Maria, the rain became lighter, but increased again by the 26th as the jet axis shifted northward. Wind velocities in the 300-mb. jet were 100 kt. or more during the periods of heavy rain and reached a maximum of 175 kt. on the night of December 21.

7. VERTICAL MOTION

When computed vertical velocities were compared with rainfall intensities, the results were rather disappointing. Vertical motion charts (fig. 6) were reproduced from the operational maps of the Joint Numerical Weather Prediction Unit and are representative of the 11-day period. The instantaneous vertical velocities plotted on the charts were computed in mm./sec., and the isopleths were drawn in cm./sec. Computation of these values incorporated only adiabatic and vorticity concepts; no provisions were made for orographic effects or convection in conditionally unstable air. These values were averaged over an area of approximately 150,000 square miles and do not represent maximum vertical motion.

On December 19, the second heaviest period of precipitation, the vertical motion at the 800-mb. level over northern California (fig. 6a) ranged from .5 cm./sec. to .8 cm./sec. At the 550-mb. level, vertical velocities were two or three times greater than those at 800 mb. (table 1). Investigations of vertical motion by Pennsylvania State University [7] have shown that an 800-mb. vertical ve-

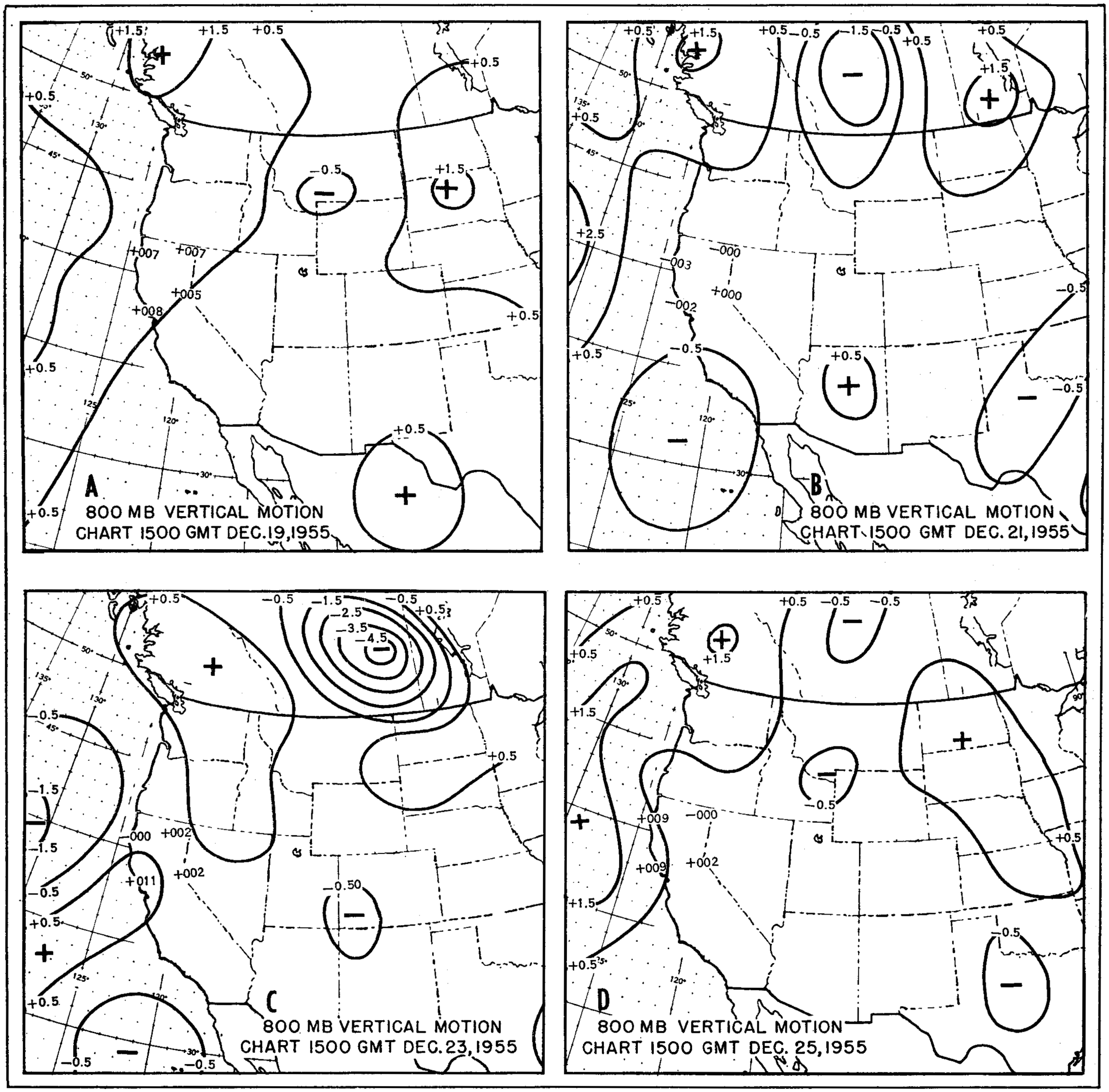

FIGURE 6.—1500 GMT charts of instantaneous vertical motion at 800-mb. level based on Joint Numerical Weather Prediction Unit computations with velocities analyzed in cm./sec. (a) December 19, (b) December 21, (c) December 23, and (d) December 25, 1955.

locity of .6 cm./sec. or more gives just about an even chance for rain or fair weather.

Vertical velocities for December 21 (fig. 6b) indicated downslope motion along the Pacific coast with little or no activity in the Sierras. Rainfall did decrease on this date, but continued to fall in significant amounts. On December 23 (fig. 6c), instantaneous velocities showed a maximum of 1.1 cm./sec. over the San Francisco area, only small velocities in the Sierras, and downslope motion at Eureka.

At the 500-mb. level (table 1), velocities on the 22d were seven to eight times greater than those at the 800-mb. level. This seemed to indicate that most of the lifting was occuring at the upper levels and was substantiated by the fact that the high-level Sierra stations received their greatest precipitation during this period (table 2).

TABLE 1.—*Daily Vertical Velocities at 1500 GMT (mm./sec.), December 16–27, 1955*

Date	16	17	18	19	20	21	22	23	24	25	26	27
San Francisco:												
800 mb	000	004	008	008	002	−002	−006	011	−000	009	005	−004
550 mb	001	009	024	017	000	−009	−021	024	003	023	012	−008
Eureka:												
800 mb	008	005	016	007	004	−003	−005	−000	002	009	007	000
550 mb	014	011	029	016	014	−007	−006	003	012	028	023	−001
Mt. Shasta:												
800 mb	010	003	009	007	000	−000	−002	002	001	−000	009	005
550 mb	020	007	026	018	008	−002	000	016	012	012	029	014
Blue Canyon:												
800 mb	000	−000	004	005	−000	000	−003	002	−003	002	005	000
550 mb	004	−000	020	013	−001	−004	−011	013	007	010	020	008

Finally, on December 25, another area of rising motion appeared (fig. 6d) in conjunction with the last Low of the series and its accompanying frontal system. These vertical velocities were about the same as for the preceding periods, yet precipitation amounts were much smaller.

The vertical velocities (table 1) were neither excessive nor capable of producing as much precipitation as occurred over northern and central California. It was estimated that given a moist tropical airmass with dewpoints of 58° F. to 60° F., a vertical velocity of 1 cm./sec. or about 118 ft./hr. would yield less than a half inch of precipitation in a day. On the other hand, vertical velocities due to orographic effects appeared to be quite strong. Because of the complexities, no orographic vertical velocities were computed; however, to illustrate the situation, the results of Paulson's [8] computation of vertical velocities for Inskip, in the Sierras northwest of Blue Canyon, are presented. Paulson found that a 45-m. p. h. wind blowing at right angles to the ridge near the 3,000-ft. level would result in a vertical velocity of 30 m./sec. up to the 15,000-ft. level. This excessive value was due to the rugged terrain in the Inskip area. It is estimated that a considerably less rugged slope, 1:50 for example, would produce a vertical velocity close to 40 cm./sec. with a 45-kt.-wind.

These values of vertical velocity are presented to emphasize the dependency of heavy California rainfall on a strong moist flow of air. Furthermore, the duration of such a flow determined the amount of rain. In considering the entire storm period, it is estimated that the 850-mb. wind at Oakland was 40 kt. or greater for at least 48

TABLE 2.—*Precipitation amounts and percentage of normal for December 1955 and periods before and during the storms of December 16–26. All percentages are based on monthly normals. Data from Local Climatological Data for individual stations except as noted in footnotes*

	Elev. (ft.)	Dec. normal	Dec. 1955	Percent of normal	Total Dec. 1–14	Percent of normal	Total Dec. 15–28	Percent of normal	4-Day totals, December 17–20	21–24	25–28
COASTAL STATIONS											
Tatoosh Island		6.96	9.00	129.3	4.90	70.4	4.10	58.9	1.00	2.49	.51
Astoria		13.21	16.57	125.4	6.66	50.4	9.87	74.7	2.31	4.75	1.27
North Bend [1, 2]		9.79	------	------	------	------	17.20	175.7	------	------	------
Crescent City [1, 3] (16)		11.90	------	------	------	------	13.09	110.0	4.10	3.93	4.46
Eureka		6.09	11.63	191.0	3.26	53.5	8.35	137.1	3.70	2.73	1.68
Point Arena [1, 2]		------	------	------	------	------	10.42	------	4.51	3.04	1.89
San Francisco		4.07	11.47	281.8	3.49	85.7	7.31	179.6	1.42	4.28	1.37
Oakland		3.42	11.29	330.1	3.56	104.1	7.52	219.8	2.03	3.54	1.75
Santa Cruz [1, 3] (17)		4.24	------	------	------	------	12.78	301.4	2.10	8.91	1.73
Santa Maria		2.61	4.82	184.6	.73	28.0	4.03	154.4	.04	3.32	.67
Burbank		2.86	1.31	45.8	.88	30.8	.42	14.9	0	.24	.18
STATIONS IN COAST RANGE											
Cummings [1, 3] (17)	1324	13.47	------	------	------	------	45.26	336.0	21.18	19.05	6.03
Skaggs Springs Los Lomas Ranch [1, 3] (08)	1930	11.57	------	------	------	------	29.31	353.3	13.07	13.05	2.37
Hobergs [1, 4]	2980	11.43	------	------	------	------	31.60	276.5	------	------	------
Angwin [1, 3] (19)	1815	5.81	------	------	------	------	26.40	454.4	16.05	9.23	.02
Mount Hamilton [1, 3] (22)	4209	5.01	------	------	------	------	15.93	317.9	3.10	11.44	1.39
INLAND VALLEY STATIONS											
Medford	1312	3.13	8.77	280.2	2.12	67.7	5.73	83.1	1.59	4.12	.17
Vollmers [1, 4]	1359	11.53	------	------	------	------	18.62	161.5	------	------	------
Red Bluff	341	4.23	7.71	182.3	3.24	76.6	4.25	100.5	2.46	.64	.73
Sacramento	25	3.19	12.20	382.4	1.79	56.1	10.13	317.6	4.37	3.82	1.61
Fresno	331	1.63	6.73	412.9	1.95	119.3	4.60	282.2	.21	3.63	.76
Bakersfield	489	1.03	.50	48.5	.42	40.8	.08	7.8	0	.01	.06
STATIONS ALONG SIERRAS											
Mount Shasta	3544	5.39	17.48	324.3	2.29	42.5	14.86	275.7	6.18	5.77	2.81
Downieville [1, 4]	2965	10.51	------	------	------	------	26.95	256.4	------	------	------
Deer Creek [1, 3] (17)	3700	10.96	------	------	------	------	37.32	340.5	12.44	19.73	4.12
Blue Canyon	5280	8.75	45.12	515.7	8.48	96.9	35.82	409.4	11.48	19.20	3.97
Calaveras Big Trees [1, 3] (08)	4696	8.95	------	------	------	------	28.55	318.9	7.99	16.86	3.70

[1] Preliminary report, data incomplete.
[2] From synoptic teletypewriter reports, supplemented by data on River Services Daily Maps, figured for 24-hr. periods starting at 0400 PST.
[3] From [11].
[4] From [12], Dec. 26, 1955.
( ) Time (PST) at which each 24-hr. period ends.

hours (fig. 10) and therefore was capable of producing rainfall exceeding 25 inches in the mountainous areas (fig. 8).

Winds of this magnitude and duration were used in computing orographic precipitation as great as that described in [5]. In figure 61 of that report, about 40 percent of the seasonal normal rainfall over the Yuba and Feather River Basins is required for the maximum possible storm. Seasonal normals, in figure 22 of that report, for the western slopes of the Sierras ranged from 50 to 90 inches of rainfall. Furthermore, it was shown in table 59, that the maximum possible storm would produce 20.0 inches in 48 hours in the Yuba basin and 23.6 inches in 72 hours. Amounts in the Feather River Basin were 5 to 6 inches less than those for the Yuba. In the 1955 storm period, 48-hour point rainfall amounts due to 45-kt. winds approached the 72-hour maximum storm values for the smaller basins.

8. TEMPERATURE FEATURES

There was considerable evidence that tropical air was available to assist in the production of the heavy rains in northern and central California. Ship reports off the Pacific coast reported dew points in the upper fifties except around December 22 when several values in the low sixties were observed. Vederman [9] has written that the —20° C. isotherm at the 500-mb. level delineates the northern limit of the tropical air at that level. On the night of December 21, P. S. T., Oakland's 500-mb. temperature reached a maximum of —11° C., and the freezing level in the Sierras rose to the 12,000-ft. level. In this same period, rain was reported near the 10,000-ft. level at Yosemite, a most unusual wintertime occurrence. In the four-day period ending December 23, as much as 2½ feet of snow melted away at the higher elevations. At well-exposed sites on December 22, it was estimated that melt water was being added to the flood runoff at daily rates as high as 4 inches at the 5,500-ft. level and 1.7 inches at the 7,000-ft. level.

During the period December 16–26, the overall temperature features were most clearly indicated by departures from normal of the 1000–500-mb. thickness. A 200-ft. rise in thickness is equivalent to a 5.4° F. rise in the mean virtual temperature of the thickness column [10]. Departures for northern and central California were more than 200-ft. above normal during the peak rain periods of December 19 and 22 (figs. 7a and 7b). Somewhat cooler air prevailed on the 26th (fig. 7c), and less rainfall was noted than for the preceding periods. Daily departures were estimated for Red Bluff and plotted on figure 5a for comparison with daily precipitation amounts and the latitudinal position of the jet stream over the Pacific coast. As would be expected, the period of greatest average rainfall coincided with the period of warmest air; Red Bluff reached a maximum departure of 500 ft. above normal on December 21, PST.

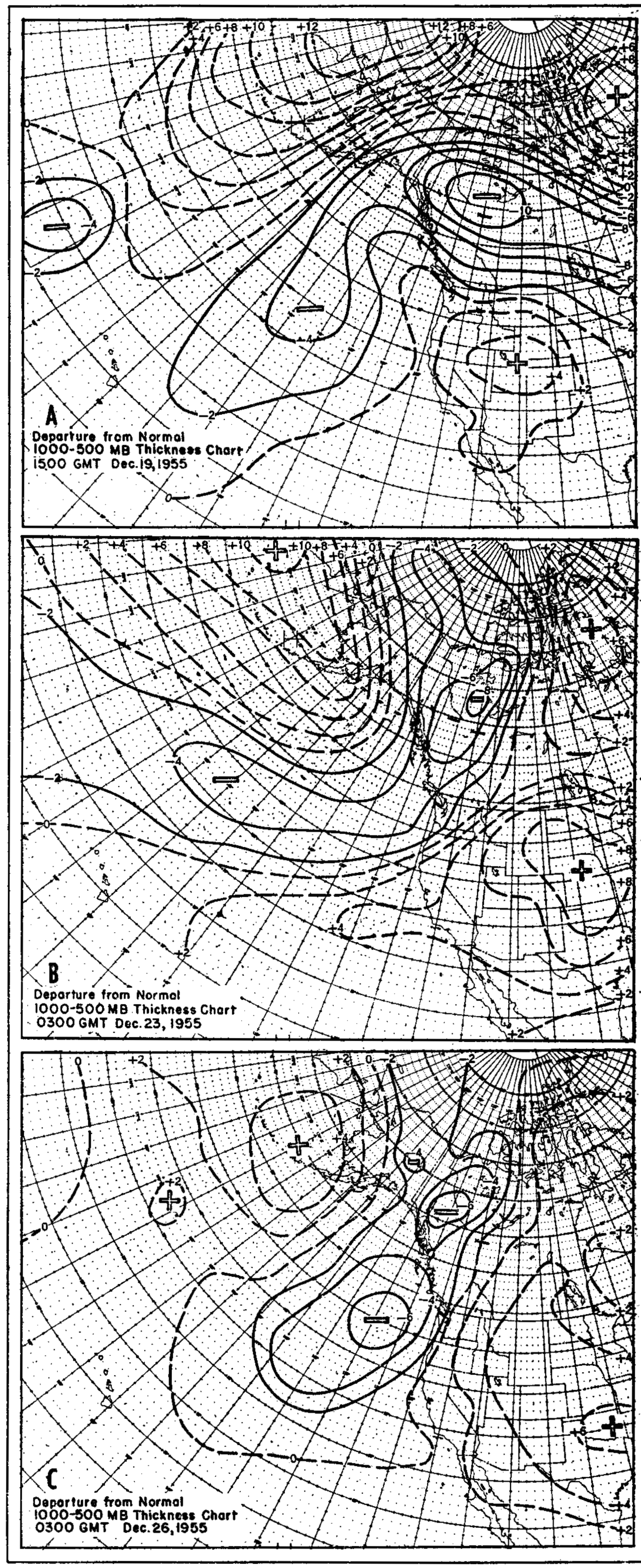

FIGURE 7.—Overall temperature features are represented by the departures of the 1,000–500-mb. thickness from normal: (a) 1500 GMT, December 19, (b) 0300 GMT, December 23, and (c) 0300 GMT, December 26, 1955. Values are in 100's of feet.

9. RAINFALL DISTRIBUTION

A chart of the rainfall pattern for the period 16th through the 24th based on preliminary reports [11], is given in figure 8. The major features of the pattern are controlled by the topography. While an objective separation of the orographic effect from other factors contributing to precipitation would be extremely complicated, it was possible to draw some conclusions from a careful comparison of the pattern with a topographic map.

Along the coast the most pronounced maxima, and the record-breaking amounts, occurred between Eureka and Monterey Bay. This stretch presents a relatively low orographic barrier; the ridge line rises to little above 3,000 feet, whereas farther south it goes to 5,000 and, to the north, well above 5,000 ft. The elongated maximum, enclosed by a 30-inch line, close to the coast south of Eureka, is very interesting because it occurred over a narrow section of the coastal mountains, between the Eel River and the Pacific, with a ridge line generally below 3,000 feet. Between this range and Red Bluff a more widespread section of the coastal range, centered around Mount Linn, presents a barrier well above 5,000 feet, yet this area showed less rain. It is true that no reports are available from the area where another maximum should have occurred but a check of point reports bears out the existence of some anomaly. Lake Mountain Ranger Station, just east of the Eel River about 60 miles south-southeast of Eureka at an elevation of 3,170 feet, reported less than 20 inches while Cummings, 15 miles southwest of Lake Mountain at an elevation of 1,324 feet, is credited with over 35 inches. Charts of river flow are given in [5]. The Mad River, which rises on the west slope of Mount Linn and enters the Pacific north of Eureka, exceeded its January 1953 record by a ratio almost as great as that shown by the Eel River. It is possible that there was more rain than indicated for the Mount Linn area but the extent by which the area around Red Bluff and, less noticeably, Eureka failed to match the records of Sacramento and Mount Shasta confirms the presence of a relative rain shadow which will be referred to later.

Along the Sierras the precipitation maximum is found between the higher reaches of the American and Feather Rivers, with two centers of over 30 inches, one around Blue Canyon more than 5,000 feet above sea level and the other just to the northwest at about 4,000 feet. This is a section of the Sierras which is relatively low, 7,000 to 9,000 feet, compared to 9,000 to 12,000 feet south of the American River. A check of the elevation of stations along the foothills which reported between 10 and 15 inches of rain shows a progressive relation; stations in this band are only about 500 feet above sea level in the Feather River area, above 1,000 feet just south of the American River, and above 2,000 feet northeast of Fresno.

The distribution of precipitation at Red Bluff was rather

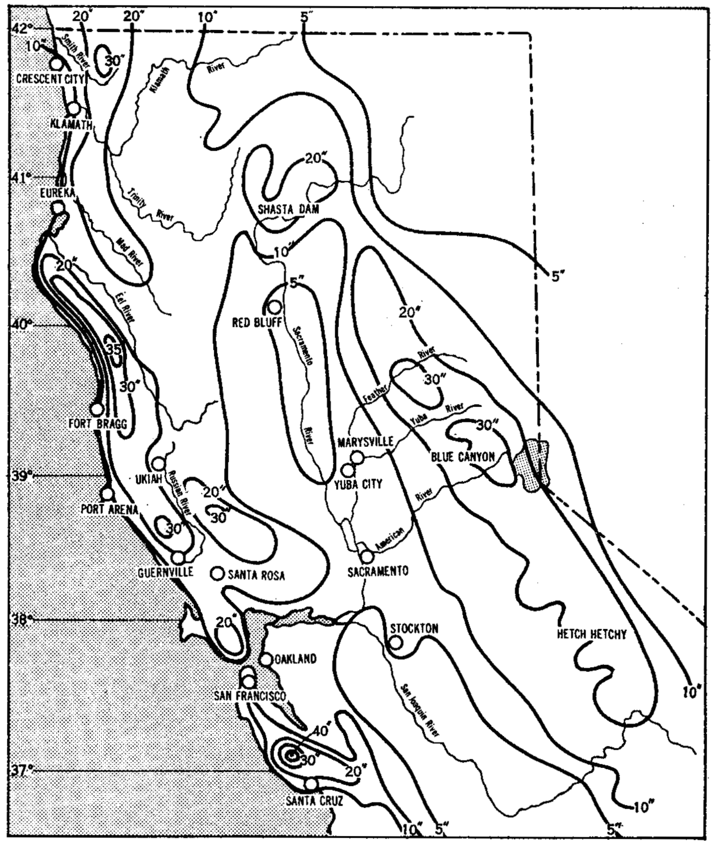

FIGURE 8.—Isohyet map of central and northern California for the period December 16–24 inclusive, reproduced from a report prepared by the Corps of Engineers [11] and based on preliminary data. Strong orographic influences are indicated by the large rain maxima along the mountain ridges.

unique. During December 15–27, rainfall there was above December normal, yet adjacent stations (table 2) reported considerably more than their normal—up to four times more. Sacramento, having similar normals, is considered a reasonable comparison in this case. In the past, the rainfall distribution at Red Bluff has been largely attributed to the direction of flow and to the presence of a cool dome over the area in advance of warm fronts [5]. During the peak rain periods in this case (fig. 10), Oakland's average 850-mb. wind was from 210° on December 19, 240° on December 23, and 210° on December 26. More precipitation fell at Red Bluff in the first and last rain period than on the 23d, showing a dependency on south-southwesterly winds. Too, more rain occurred during the December 17–20 period, since that situation featured the only good warm frontal surface (fig. 1a) to pass over northern California. Undoubtedly, the smaller amounts reported on the 26th were mostly due to less available moisture than for the preceding periods.

Another interesting aspect of Red Bluff's precipitation was that the rainfall appeared to be closely related to the position of the storm track with respect to the station. On December 19, the track of the waves was to the north

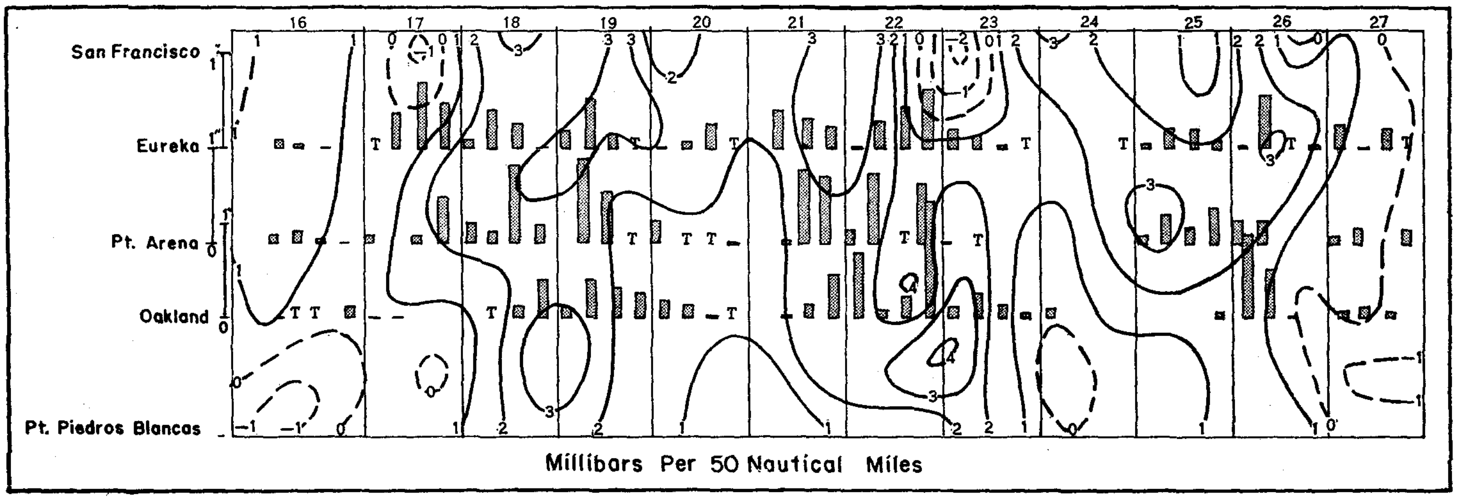

FIGURE 9.—Bar graph of 6-hour rainfall totals at Eureka, Point Arena and Oakland, superimposed on a time chart of the intensity of the sea level pressure gradient between eight coastal stations: North Bend, Crescent City, Eureka, Point Arena, San Francisco, Salinas, Point Piedras Blancas, and Santa Maria. Solid lines represent lower pressure to the north. Units are 1 mb. per 80 miles or approximately 15 knots onshore component of the gradient wind. December 16–27, 1955.

of Red Bluff and their rainfall was quite heavy. On the 22d, the track was nearly over the station and precipitation amounts were comparatively small. As the track shifted southward, precipitation amounts at Red Bluff were not significantly greater than those of the 22d, but Fresno incidentally, received their largest rainfall of the storm period.

10. LOW LEVEL FLOW

On the isohyetal map (fig. 8) it is seen that the importance of strong low-level flow is reflected in the rain maxima along the mountain ridges. To determine the significance of strong low-level flow at stations of low elevation, graphs were constructed comparing pressure gradients with point rainfall amounts. Bar graphs of the 6-hour rain totals at three coastal stations are presented in figure 9 and at four inland valley stations in figure 10. On the bar graphs in figure 9 is superimposed a time-latitude analysis of the sea level pressure gradient along the coast. Pressure gradients were determined at 12-hour intervals for neighboring pairs of eight coast stations, from North Bend to Santa Maria. A smoothed analysis of the gradient values was made in units of 1 mb. per 80 miles. Solid lines represent lower pressure to the north, or an onshore component of the geostrophic wind of about 15 kt. per unit.

Three bands of strong gradient appeared, December 17–19, December 21–23, and December 24–26. Each coincided with the periods of heaviest rainfall. Point Arena and Oakland responded to the gradient increases but Eureka was erratic.

With the bar graphs in figure 10 is presented a time graph of the speed of the 850-mb. wind over Oakland. It can be seen that the rise and fall of this speed corresponds very closely to the overall fluctuation of rainfall

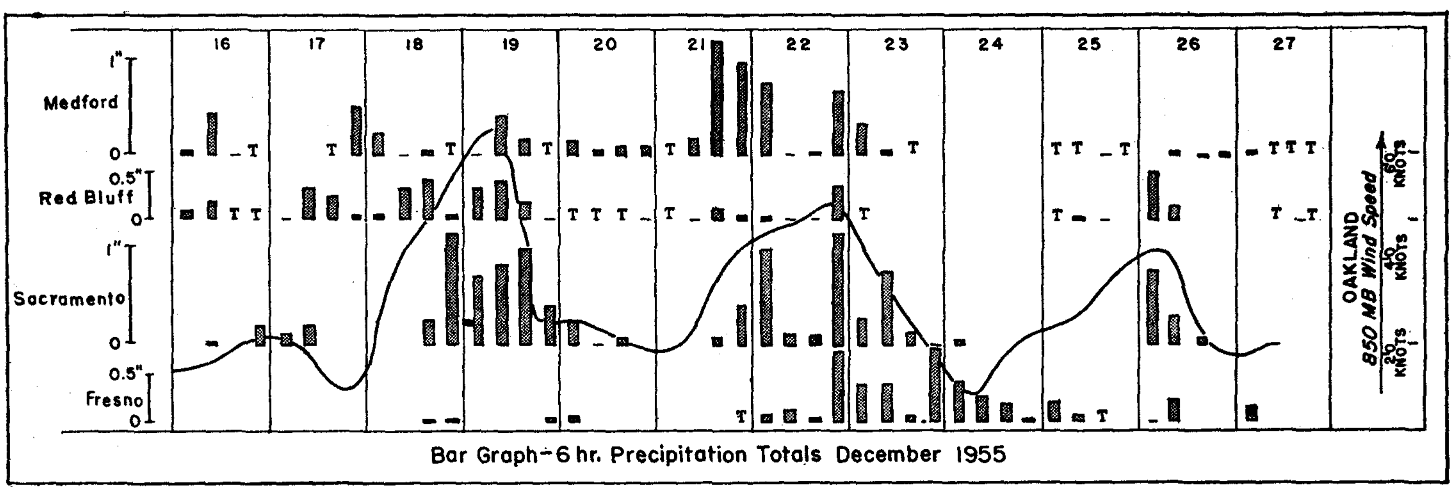

FIGURE 10—Bar graph of 6-hour rainfall totals at Medford, Oreg., Red Bluff, Sacramento, and Fresno, Calif. (scale given on left). Superimposed in single fluctuating line is graph of speed of 850-mb. wind over Oakland, (scale given on right). December 16–27, 1955.

at both Oakland and Sacramento. In addition to the general agreement throughout the period, these two stations from the 21st through the 23d were under the same airflow and showed remarkably parallel fluctuations in the six-hour rain totals. The relationship of point rainfall with 850-mb. wind speed appeared to be better than that with local sea level pressure gradients.

11. FLOODS

Flood conditions in northern and central California were the most disastrous on record for many places. Along the coastal section north of San Francisco, the destructive floods began about December 19 and crested around December 22. The Russian River flooded from Ukiah southward and was reported in the 50-ft. stage between Guerneville and the ocean. Its maximum discharge at Guerneville was 90,100 cu. ft./sec. Farther to the north, practically the entire Eel River was in flood, especially after the Redwood Valley Dam on the upper portion of the river overflowed. The development of a log jam in the river aggravated the situation also. At Scotia, the Eel River discharged a maximum flow of 500,000 cu. ft./sec., exceeding its previous record of 345,000 cu. ft./sec. established in December 1937. Both the Mad River and the Klamath River were higher than the record set in January 1953. In the town of Klamath, water was reported 15 to 18 feet deep as the Klamath River discharged 400,000 cu. ft./sec., beating its previous record by nearly a third. The Smith River and several smaller streams were also on rampage and exceeded their record flood stages.

Communities along the Eel River and the Klamath River were hit especially hard by the floods. Five small towns with populations close to 500 were reported "smashed" or "wiped out": Elinor, Pepperwood, and Weott on the Eel and Klamath, and Klamath Glen on the Klamath River. At Pepperwood, scarcely any house was reported on its foundation, and those houses not washed away were smashed.

South of San Francisco, creeks and rivers were also out of their banks, but the floods were not as severe as those in the north. Santa Cruz reported three deaths and 6 feet of water in the business district as the San Lorenzo Creek overflowed, reaching its greatest height since February 1940. A little to the north along the peninsula, more than 1,000 people were forced to evacuate their homes in Palo Alto when the San Franasquita Creek spilled over its banks and pushed two feet of mud and water into many homes lying in low areas. Some flooding was also reported in Burlingame, South San Francisco, Piscadero, and Linda Mar.

Beginning around December 22, flood conditions prevailed in the Sacramento Valley, and nearly every place reported record-breaking stages except on those streams where runoff was controlled by reservoirs. Perhaps, the most important flooding occurred along the lower reaches of the Feather River. At Yuba City, the Feather reached a flood stage of 82.4 feet on December 24, exceeding the previous record of 71.7 feet established in November 1950. Marysville, just across the River from Yuba, was evacuated around December 21 as flood waters seemed imminent. Its population was sent to Yuba. Ironically, a levee break on the Feather River flooded Yuba on December 24, forcing about 8,000 Yuba residents plus refugees from Marysville to seek higher ground. The Yuba business district reported water up to 15 feet deep. With Yuba being flooded, the pressure was removed from Marysville levees, dropping the water level 9 inches within 2 hours after the levee break on the Feather River. Marysville was not flooded.

On the Sacramento River, the water was largely controlled by reservoirs, and conditions were not as bad as those elsewhere. At Sacramento, the river climbed to within 6 inches of the levee top at the foot of H street, reaching a stage of 28.7 feet on December 23. Record flood stage at Sacramento was established in November 1950 with 30.2 feet.

Flooding was also reported at Stockton on the San Joaquin River system. Again, most of the streamflow was controlled and the river stages did not exceed the record of December 1950. Approximately 3,000 people were forced from their homes in Stockton as 3 to 4 feet of water poured into the southeastern section of the town on December 24.

By December 24, rivers in northern and central California had crested and flood waters were receding. West coast newspapers reported extensive damage and described the floods as the worst in history. They added that the storm period was characterized by a heavy almost continuous downpour that caused a runoff so great that the natural watershed could not handle it.

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